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PLASMAPHERE AND MAGNETOSPHERE STRUCTURE  
FROM ISEE-1 AND DE-1

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### I. Introduction

The purpose of this grant has been to investigate the density structure of the plasmapause region, using the two satellites, ISEE-1 and DE-1 to obtain complementary radial and latitudinal profiles. Data from the plasma wave receivers were to be used to obtain total electron density, and from the ion mass spectrometers to determine thermal plasma morphology.

This program was partially successful, in that the general relationships derived from ISEE-1 could be applied to the DE-1 data. A frustratingly small percentage of the data overlapped in truly helpful ways, however. In general, it could be counted on that one of the satellites would be off at the wrong time, or in the wrong instrument modes. This points out the need for strong coordination efforts in future programs to insure that complementary data sets are available (e.g. POLAR and WIND, with GEOTAIL). Operational duty cycles of greater than 50% will be necessary, if overlaps are not specifically planned.

### II. Radial Structure

Electron density profiles were obtained for over 25 sets of orbits where the ISEE-1 satellite passed through perigee near DE-1. Several dozen more orbits were analyzed, and proved unsuitable for various reasons. The first major result to arise from the analysis of the ISEE-1 data was the (re)-discovery of the L-4 density profile exhibited by the

plasmapause region (Chappell et al, 1970). This has been emphasized in the way the data are plotted, as shown in Figure 1. Figure 1a shows an ISEE-1 density profile from April 19, 1982 (day 109), with density plotted vs. L. This is an outbound segment at local dusk (18-21 LT). A sharp plasmapause is found at  $L = 2.7$ , 18 LT, 18 degrees magnetic latitude. After that, the decline is slower, in fact  $L^{-4}$  as indicated by the solid line, which is normalized to  $100 \text{ cm}^{-3}$  at  $L = 4.5$ . This latter set of values, used generally throughout our analysis, is chosen for convenience in comparing with DE-1 data, and is consistent with recent findings by R. R. Anderson that the normal radius for a  $100 \text{ cm}^{-3}$  isodensity contour is  $L = 4.5$  (Huntsville Modeling Conference, October, 1986). If the data are normalized by  $L^{-4}$ , Figure 1b results. The data form a nearly horizontal line, at least from  $L = 3$  to 5, with a slight shift upward from  $L = 5$  to 7. This shift is real (i.e. not a statistical fluctuation), and not atypical.

Even when the density profile is not constant over large ranges of L, it is often true that  $L^{-4}$  profiles are applicable piece-wise. Figure 2 shows an example from June 1, 1982 (day 152), at 17 LT. The normalized density profile is flat from  $L = 3$  to  $L = 5.8$ , then drops sharply, and is again flat from  $L = 6.0$  to 7.0. Such structures are attributed to a plasmasphere boundary subject to intermittent erosion (due to substorms), followed by refilling at constant rates. Sharp boundaries such as the one found here are therefore indicative of

substorm activity which did not disturb the plasma inside the  $L = 5.8$  boundary.

This work also allowed for the (re)discovery of detached plasma regions (Chappell, 1974). This is illustrated in Figure 3, again a normalized density profile vs.  $L$ . These data are from March 26, 1982 (day 85). The satellite is in the 20-22 LT sector, moving outbound, and dropping in magnetic latitude from +15 to -2 degrees. Plasmasphere densities (i.e. greater than  $100 \text{ cm}^{-3}$ ) are found inside  $L = 4.3$ . There are then lower plateaus, followed by a return to the initial profile from  $L = 6.05$  to 6.50. It can be seen that plotting these 'normalized' densities emphasizes the differences between true boundaries, and the more gradual spatial gradients which exist as equilibrium structures.

The goal of establishing the nature of the plasmapause topology requires complementary passes through the plasmapause. This was effectively achieved only twice in 1982, according to our surveys of the data. Both examples are illustrated here. Both show  $L$ -4 dependences for the ISEE-1 radial profiles, and latitude independent profiles from DE-1. Figure 4 shows the ISEE-1 and DE-1 orbits in latitude vs  $L$  plots. These data from March 16, 1982 (day 75). ISEE-1 passes is at 2040 LT at  $L = 3$ , 2141 at  $L = 4$ , and 2206 LT at  $L = 5$ . DE-1 stays between 2240 and 2300 LT during this period. As a result, the field lines crossed by ISEE-1 early during its orbit, co-rotate to the nominal DE-1 region. Figure 5 shows the ISEE-1 density profile, with  $L$ -4 profile overlaid.

The agreement is particularly good in the  $L = 4$  to 5 range. If this normalization is applied to the DE-1 data, Figure 6 results. The density profile is flat from -40 to +15 degrees, where it starts to break up. The rise at 15 degrees latitude has no apparent counterpart in the ISEE-1 data, the subsequent fall reflects the drop in density after  $L = 5$  in the ISEE-1 profile.

The second conjunction which proved useful was on May 6, 1982 (day 126). This example was used in the article on plasma heating (Olsen, et al , 1987). Figure 7 shows the ISEE-1 and DE-1 orbits. ISEE-1 moves radially outward, and down in magnetic latitude, as it rotates from 16 to 19 MLT. DE-1 approaches the equator from the opposite hemisphere, in the 19-20 MLT range. The ISEE density profile, shown in Figure 8, shows a sharp plasmapause density gradient at  $L = 3.7$ , with two regions of gradual slope at either side. The density profiles were least-square-fitted (LSF), with results indicated on the figure. The inner region drops quite sharply, with the outer region dropping a little more sharply than normally found in the outer plasmasphere. If this latter information is applied to the DE-1 latitude profile, Figure 9 results. The normalized density is found to be flat from -38 to +8 degrees.

As a result of this work, the regular analysis of DE-1 data was modified to include regular plots of 'normalized' density profiles. It was found that flat latitude profiles such as these were common, if not in the majority. The cases

which showed a clear latitude structure, which could be separated from radial structure, were somewhat rare. In particular, it was difficult to find clear cases of latitude structure in the limited set which included complementary ISEE and DE data. As a consequence, the following cases use only DE data.

### III. Latitude Structure

Two forms of latitudinal structure have been found in the data. First, a latitude structure with a local minimum at the magnetic equator was found to be a persistent feature of the normalized density profiles. Second, there was occasionally evidence of a density dropoff with latitude at 40-50 degrees magnetic latitude. Both features are indications of plasmasphere filling processes.

#### A. Equatorial Density Minimum

The density minimum at the magnetic equator is an effect associated with plasma heating at the equatorial plasmapause (Olsen et al, 1987). By means of the techniques developed under this grant, it is now possible to demonstrate the existence of the density minimum unambiguously.

The first example comes from January 8, 1982. The orbit is illustrated in Figure 10, a projection of the DE-1 orbit in SM coordinates into the 0300 local time plane. Only DE-1 data are available from this time. ISEE-1 was in the right region, at the right time, to provide useful, complementary data, but

was not operating. The satellite passes out through the outer plasmasphere as it crosses the equator, passing through a region of heated plasma, indicated by the cross-hatched area in Figure 10. Figure 11 shows the electron density, normalized for radial distance, plotted versus latitude. The normalized density drops by a factor of 3, over a latitude range of about 10 degrees, centered at the equator. The actual density profile (not shown), also shows the local minimum at the equator, with roughly equal values for the electron density on either side.

Figure 12 is a color spectrogram for the hydrogen data from the Retarding Ion Mass Spectrometer (RIMS) on DE-1, with the plasma wave data (PWI) shown in the bottom half. The heating process noted above in the orbit plot, is shown here by the large red area in the top panel, which is the Retarding Potential Analysis (RPA) for the H<sup>+</sup> measured along the spin axis (nominally 90 degree pitch angle). Higher fluxes, and higher retarding voltages, are indicative of heating. The middle panel is the spin axis for the integral H<sup>+</sup> flux. This plot shows a progression from isotropic, rammed plasma, to a pancake distribution (peaked at 90/270 degrees), back to isotropic, and finally field-aligned (peaked at 0/180 degrees).

On March 15, 1982 (Day 74), the satellite was outbound, rising up to the equator from the southern hemisphere while skimming the L = 3 field line, crossing the equator at L =

3.4, finally crossing the plasmapause at  $L = 4.5$  at 16 degrees magnetic latitude. The density profile vs.  $L$  is shown in Figure 13. The dip at  $L = 3.4$  coincides with the equator crossing, with the plasmapause occurring at  $L = 4.5$ . The normalized density profile is shown in Figure 14. This emphasizes the drop in density, which is almost a factor of 3. The thermal plasma data (not shown) again show heating effects. The cold isotropic H<sup>+</sup> and He<sup>+</sup> ions show a temperature increase, but apparently remain largely isotropic.

The third example of a density minimum occurs in a region of substantially lower plasma density, on July 18, 1982 (day 199). The orbit for DE-1 is shown in figure 15. DE-1 is in the mid-afternoon sector, and stays near  $L = 4.5$  for a substantial portion of the equator passage. The density data are shown in Figure 16. The electron density (lower panel) shows a nearly monotonic variation, with only faint indications of a local minimum at lower latitudes. Once the data are normalized, however, it is clear that the region from -20 to +20 degrees magnetic latitude is a region of reduced density. RIMS data (not shown) indicate that the plasma away from the equator is field-aligned, while at the equator the plasma pitch angle distribution is peaked near 90 degrees (e.g. pancake). This latter distribution (along with RPA analysis) is indicative of heating, again.

The three cases illustrated here illustrate the idea of a local minimum in the plasma density near the magnetic equator. This minimum is associated with heating of the thermal plasma, particularly ions (electrons not being observed on DE). The third case, above (day 199), with field-aligned ions disappearing at the equator, can be interpreted as a result of enhanced (positive) plasma potentials, reflecting the low energy (few eV) ion beams. This interpretation has been suggested previously for similar observations (Olsen et al 1987). The observations at lower L (higher density) are interpreted in a similar way. Heating of the low energy ions results in an increase of the plasma potential (of a volt or two). The ion density is then reduced ( $\exp(-q\phi/kT)$ ), and the electrons follow (basically a barometric law). Such effects will not be observed if the density is too high (heating damped) or too low (associated plasma temperatures are larger than the plasma potentials). The effect appears to be limited to a density range of 20-300 cm<sup>-3</sup>.

#### B. High/Low latitude Plasmapauses

Variations in the plasmapause L-shell often appear to vary with latitude in DE data, but such effects are difficult to separate out from anticipated processes such as local time (azimuthal) structures co-rotating past the satellite. (This was the point of combining the two satellite data sets.) One example of the high/low latitude structure which is often observed is shown from August 27, 1982 (Day 239). Figure 17 shows the orbit for this pass. The satellite is near noon,

local time, moving inward radially, and upward in latitude. Figure 18 shows the L-profile for the density. The satellite crosses the plasmapause at  $L = 5.5$ , at -22 degrees magnetic latitude, at 16 UT. The density increases as the satellite moves in to  $L = 4$ , then decreases with the same profile until 1845 UT, at  $L = 4.3$ , at +35 degrees magnetic latitude. At this point, the plasmapause is again encountered. The normalized density profile, shown in Figure 19, emphasizes this behavior. These data suggest a plasmasphere which extends to greater L at low latitude. Such a feature has been suggested by statistical surveys of the RIMS data (J. L. Green, private communication, 1983). Such a structure might be expected if the plasmasphere begins filling from the equator down. Unfortunately, these data do not rule out a simple explanation in the form of a local time structure (over almost 3 hours, or 45 degrees azimuth) rotating by the satellite.

#### IV. References

1. Chappell, C. R., K. K. Harris, and G. W. Sharp, The morphology of the bulge region of the plasmasphere, J. Geophys. Res., 75, 3848-3861, 1970.
2. Chappell, C. R., Detached plasma regions in the magnetosphere, J. Geophys. Res., 79, 1861-1870, 1974.
3. Olsen, R. C. S. D. Shawhan, D. L. Gallagher, J. L. Green, and C. R. Chappell, Plasma observations at the earth's magnetic equator, J. Geophys. Res., 92, 2385-2407,

1987

V. Programmatics

Publications submitted or published based on work under this contract are listed below. A publication tentatively titled, "The density minimum at the earth's magnetic equator" by Olsen et al, is under preparation for submission to JGR. Data have been provided to P. M. E. Decreau to extend previous work (ref 1 below) to the local dawn region. This grant led to cooperative experiments recently conducted using the University of California (UCB) electron gun on ISEE-1, to stimulate waves observable by the University of Iowa plasma wave experiment. Results from these latter experiments will be considered as the telemetry is processed.

This work was completed after the principal investigator moved to the Naval Postgraduate School, Monterey, California. The work there was supported by an internal grant from the Research Foundation of the Naval School.

1. Decreau, P. M. E., D. Carpenter, C. R. Chappell, R. H. Comfort, J. L. Green, D. A. Gurnett, R. C. Olsen, and J. H. Waite, Latitudinal plasma distribution in the dusk plasmaspheric bulge: Refilling phase and quasi-equilibrium state, J. Geophys. Res., 91, 6929-6943, 1986.
2. Comfort, R. H., Plasmasphere thermal structure as measured by ISEE-1 and DE-1, Adv. Space Res., 6, 31-40, 1986.
3. Olsen, R. C. S. D. Shawhan, D. L. Gallagher, J. L.

Green, and C. R. Chappell, Plasma observations at the earth's magnetic equator, J. Geophys. Res., 92, 2385-2407, 1987.

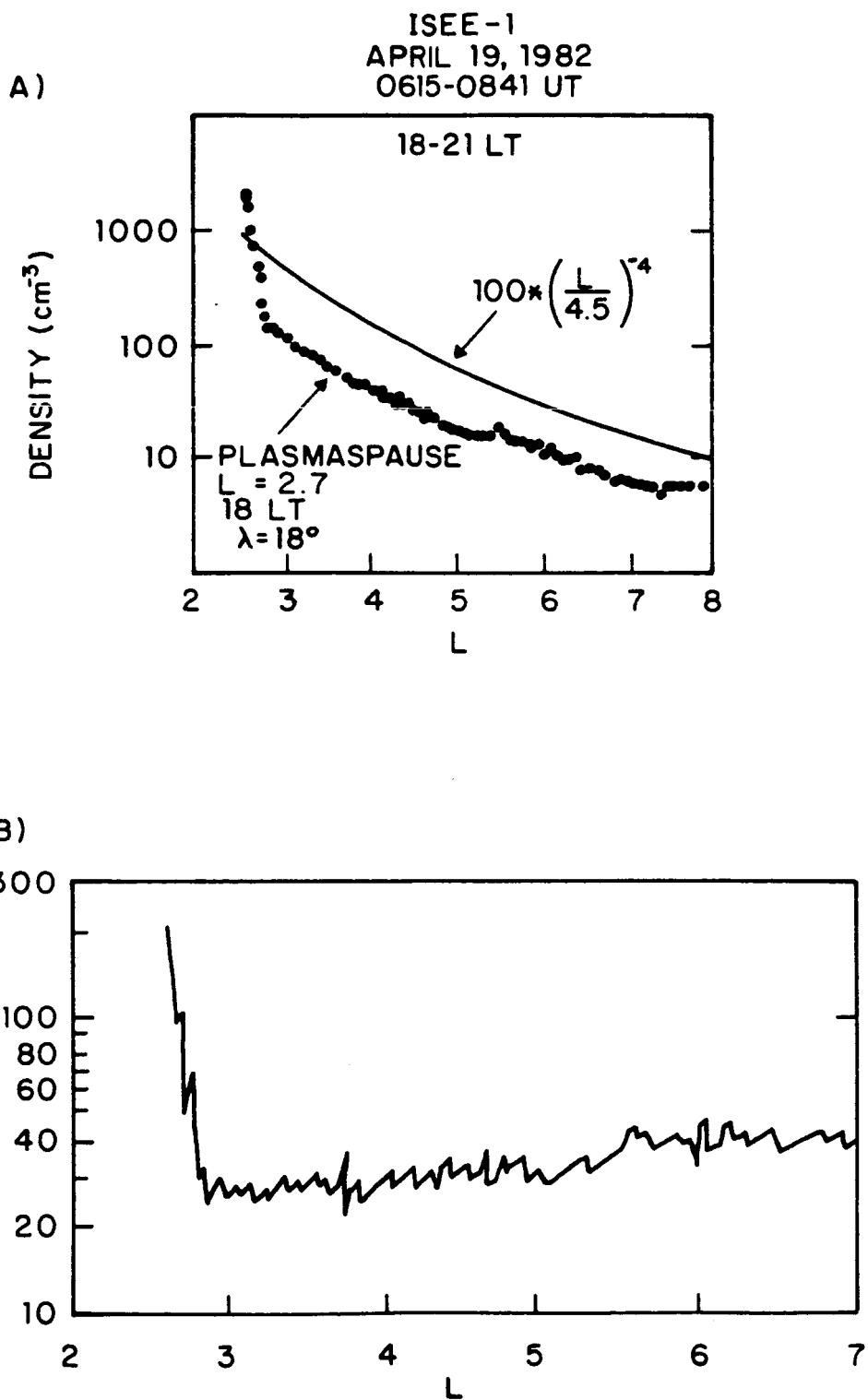


FIGURE 1

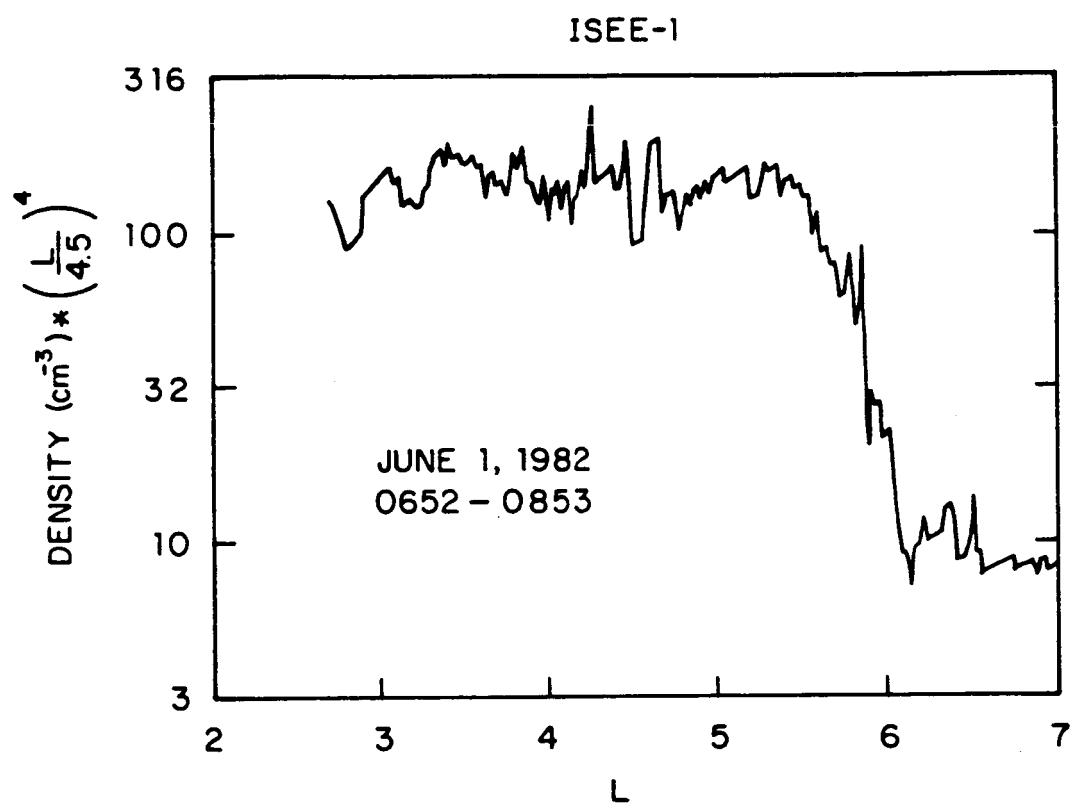


FIGURE 2

ISEE-1  
MARCH 26, 1982  
0849-1029 UT

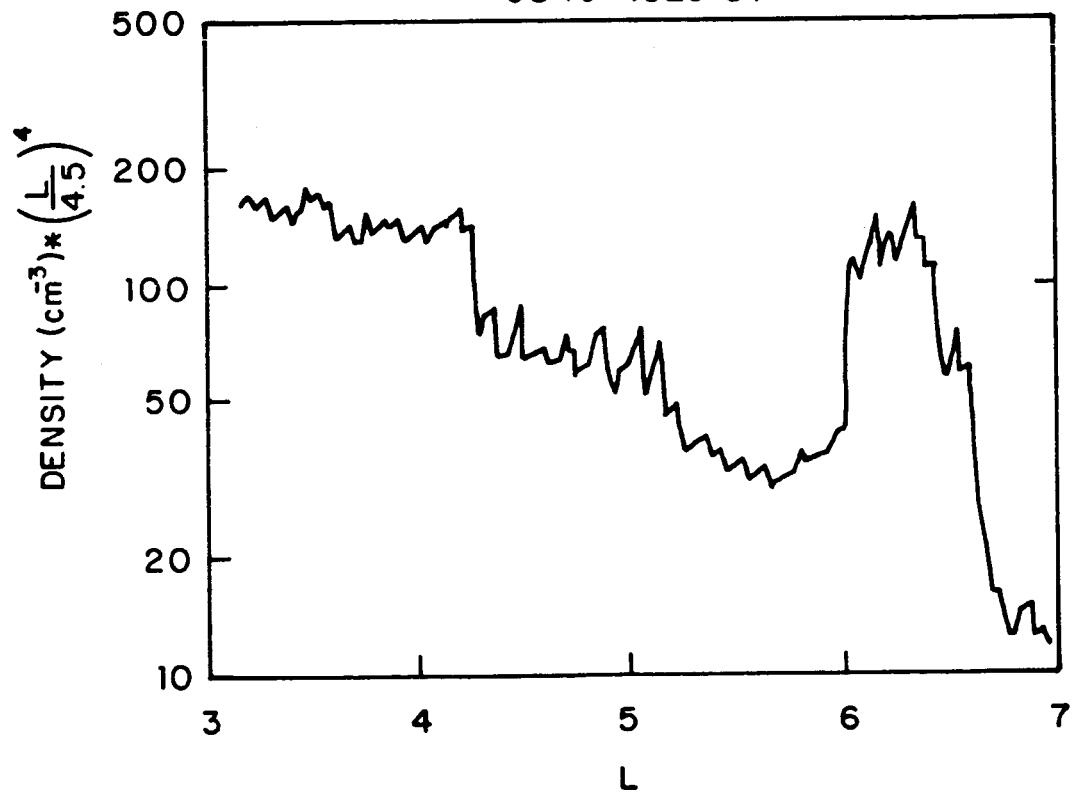


FIGURE 3

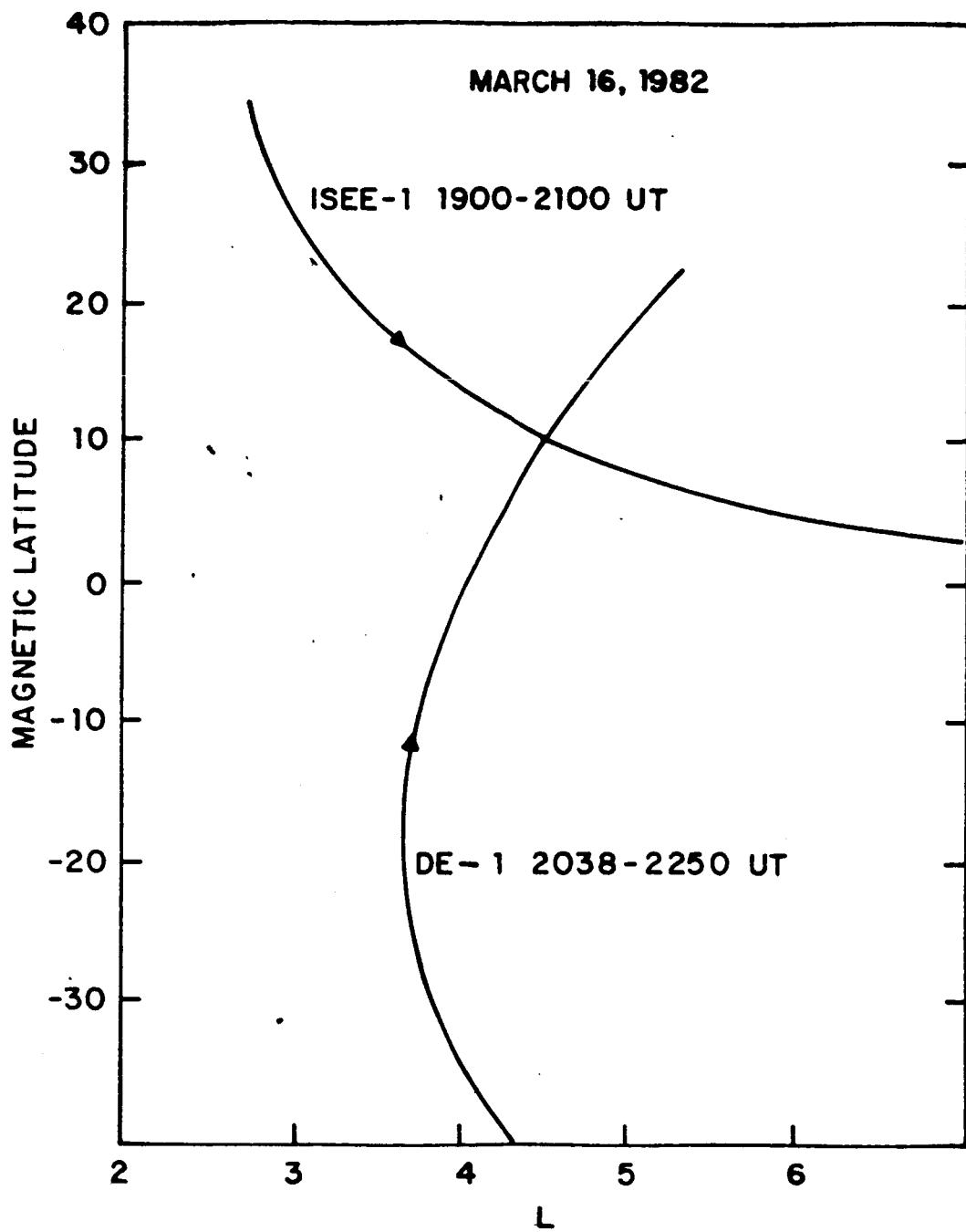


FIGURE 4

ISEE - 1  
MARCH 16, 1982

1900-2100UT

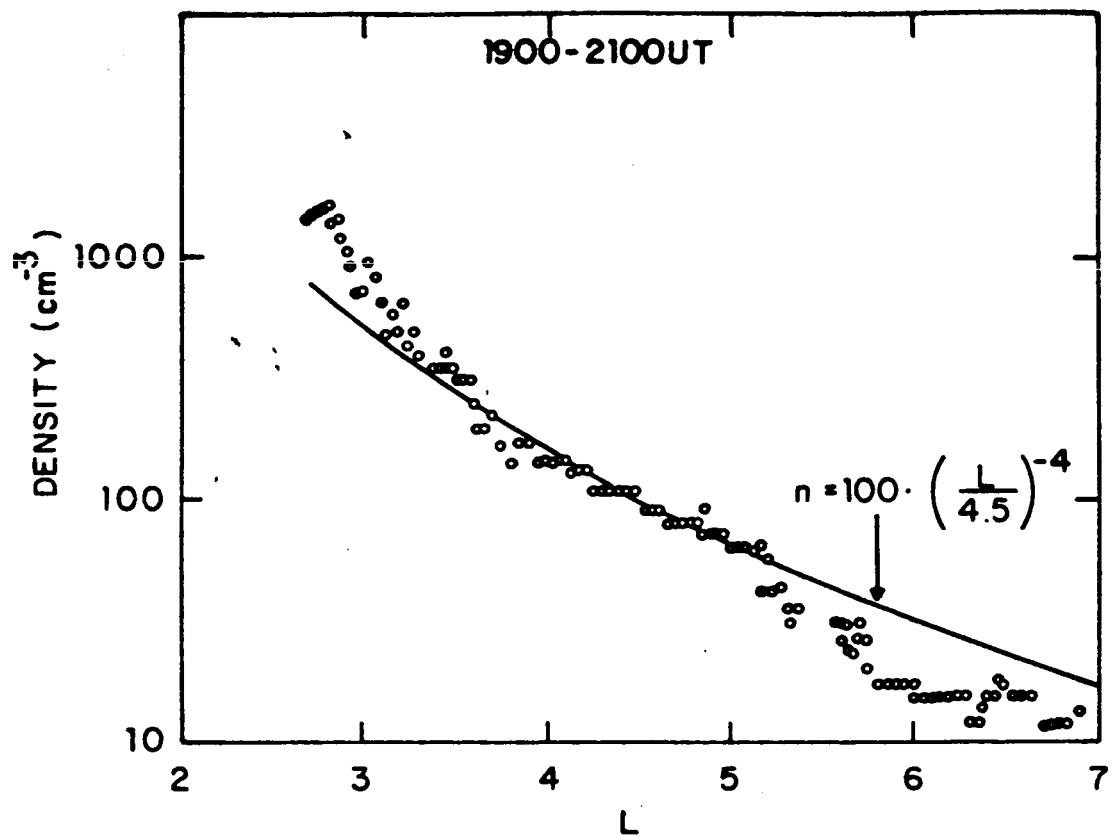


FIGURE 5

DYNAMICS EXPLORER 1  
MARCH 16, 1982  
2038 - 2250 UT

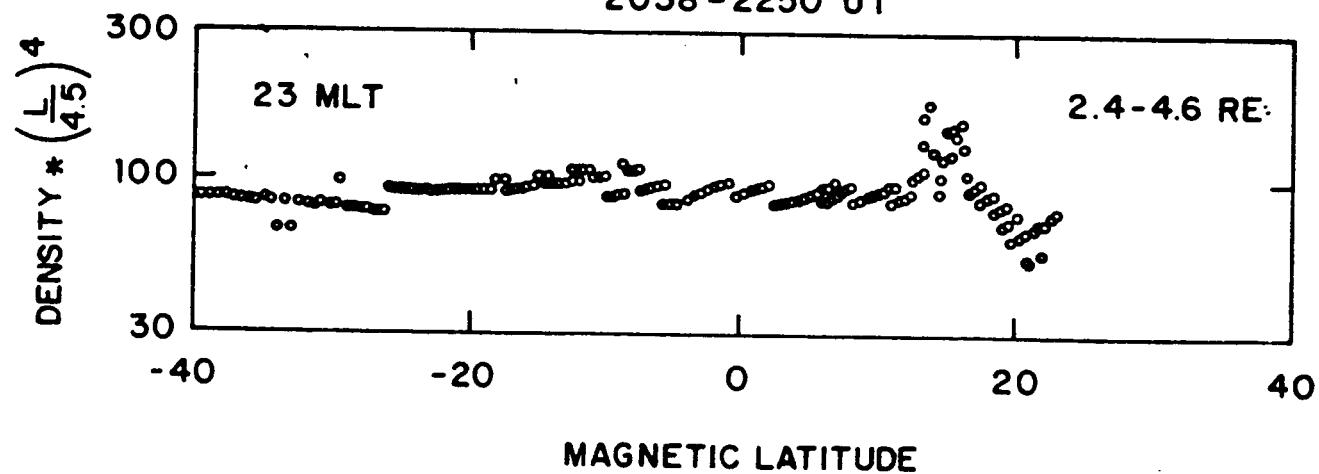


FIGURE 6

DE-1 AND ISEE-1  
MAY 6, 1982

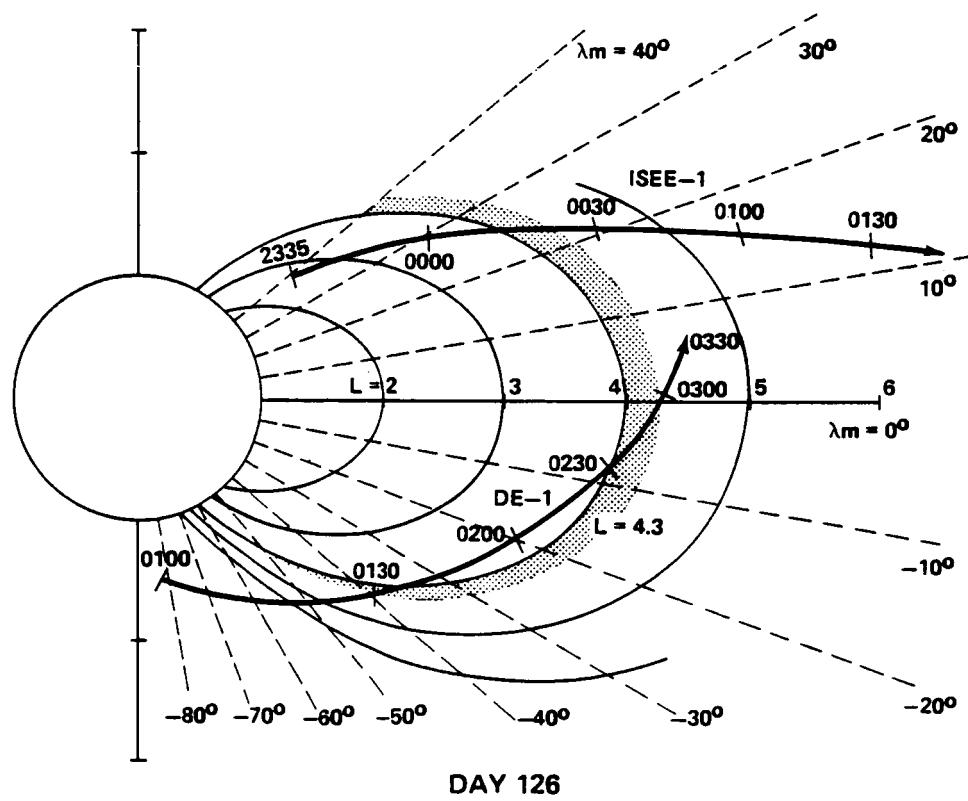


FIGURE 7

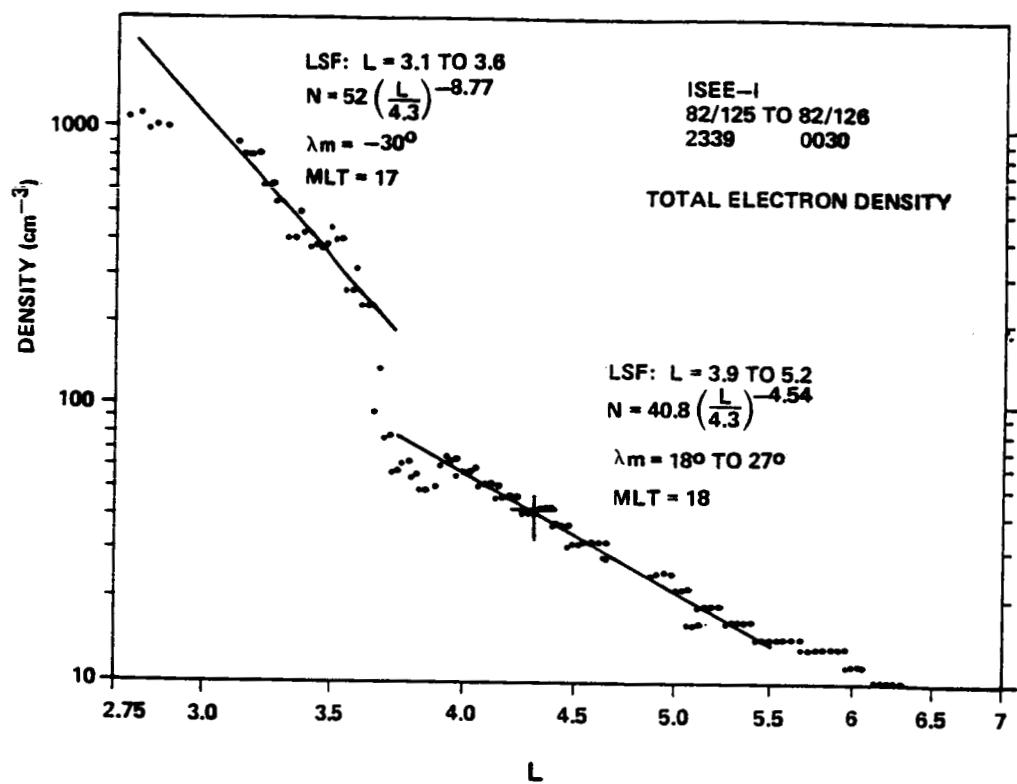


FIGURE 8

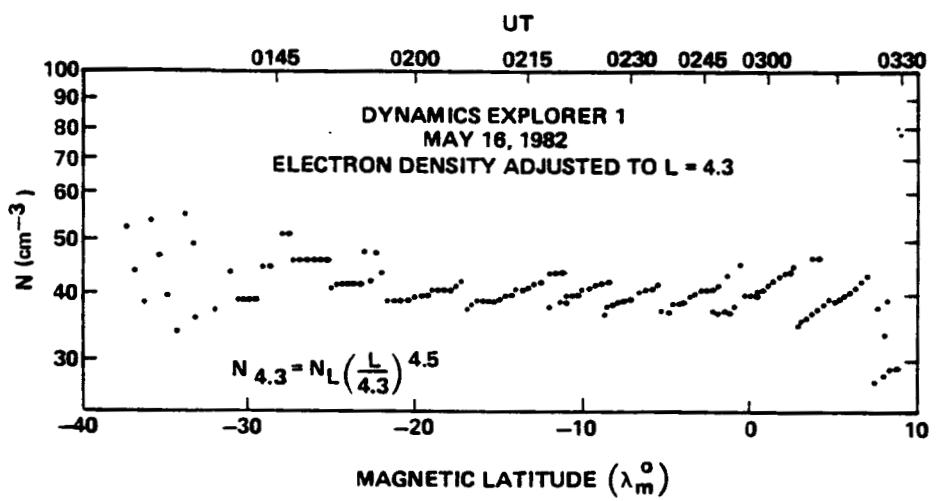


FIGURE 9

**DYNAMICS EXPLORER 1**

JANUARY 8, 1982  
SM COORDINATES

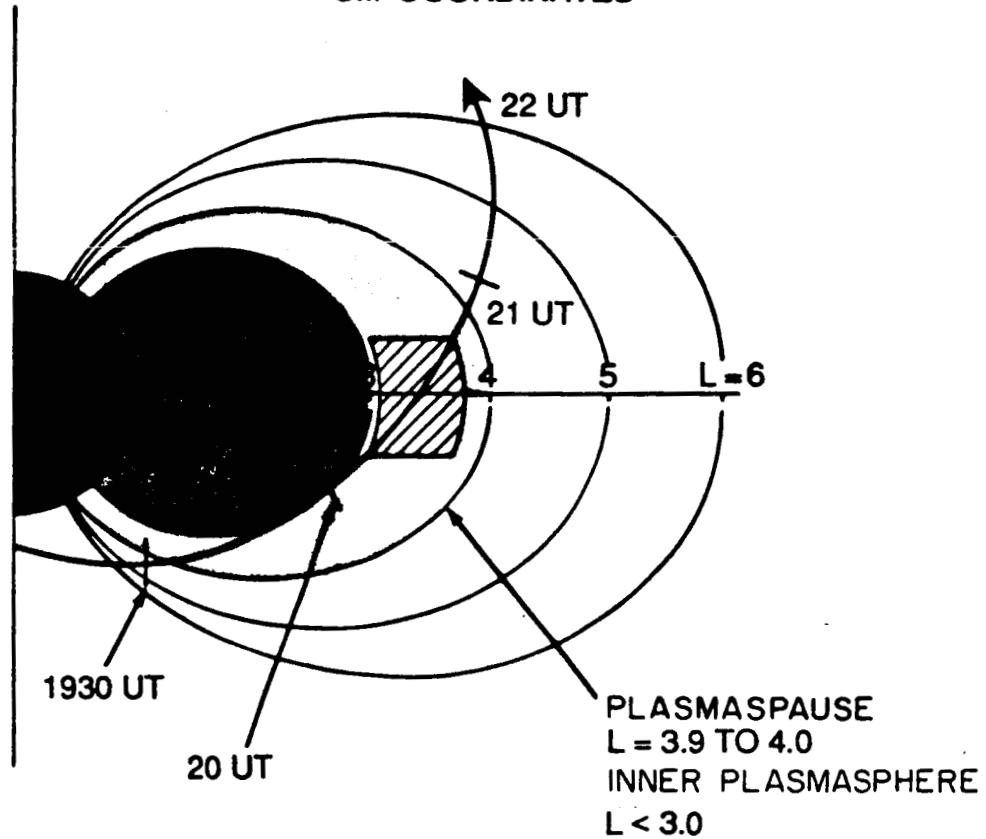


FIGURE 10

DYNAMICS EXPLORER 1  
JANUARY 8, 1982  
2000-2050 UT

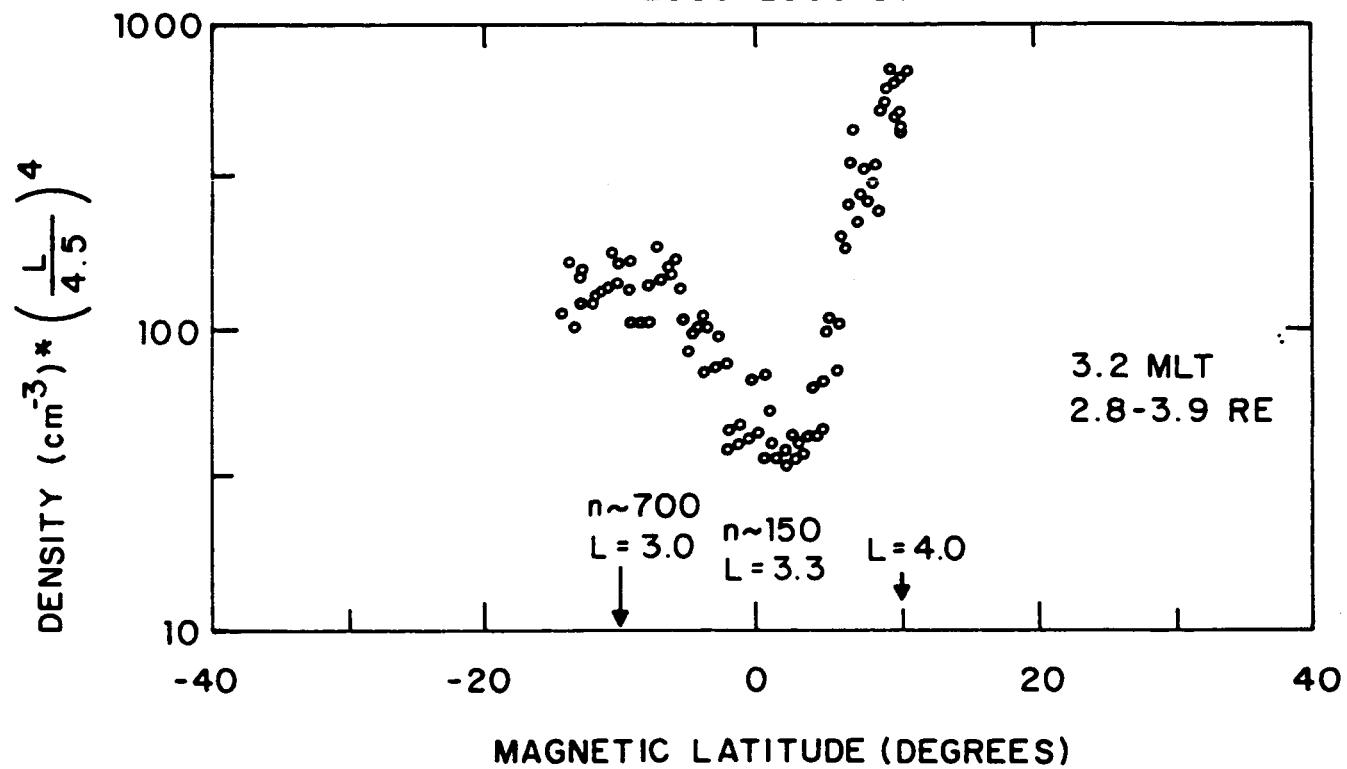
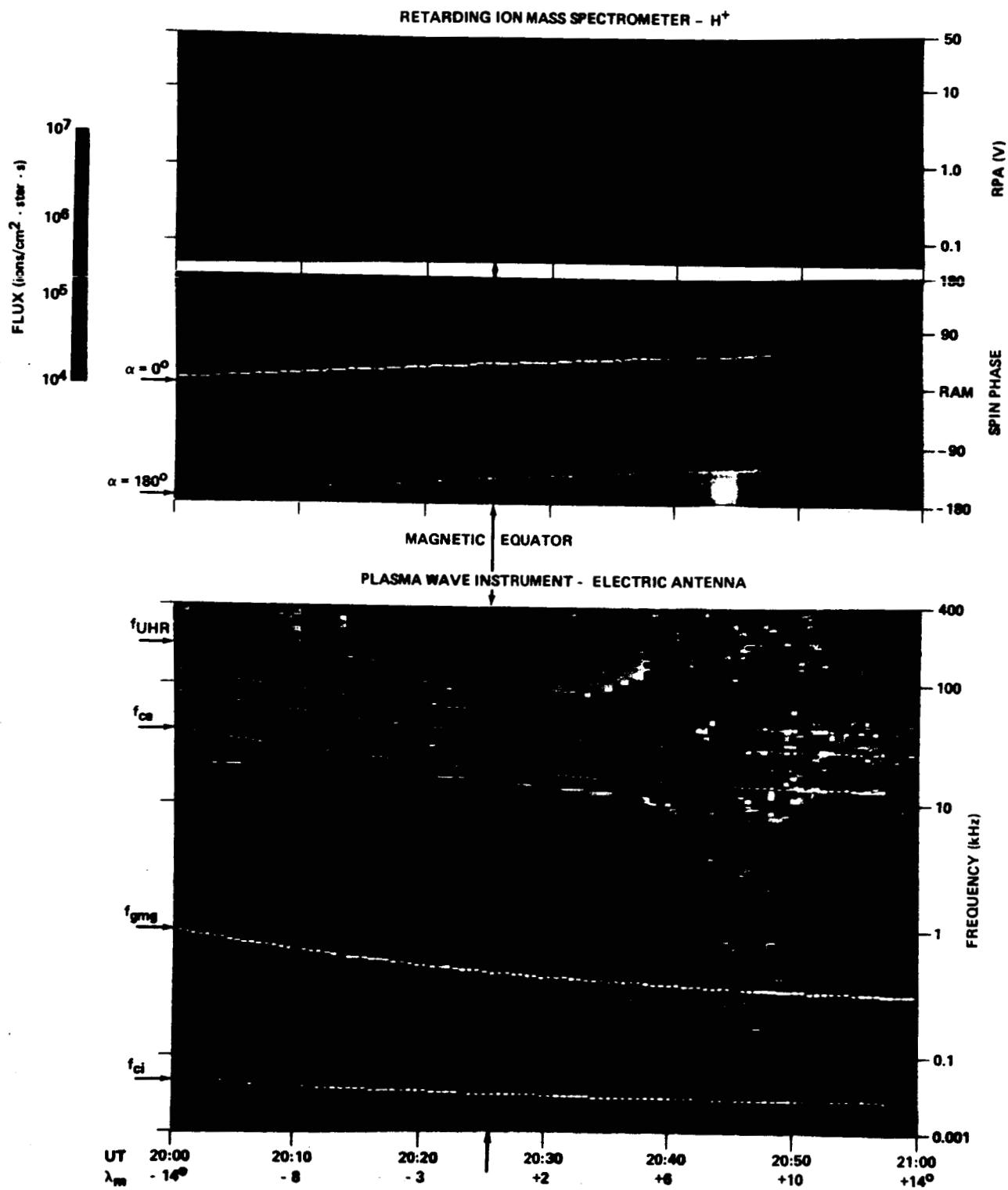


FIGURE 11

ORIGINAL  
OF POOR QUALITY

DYNAMICS EXPLORER 1  
JANUARY 8, 1982



DYNAMICS EXPLORER 1  
MARCH 15, 1982

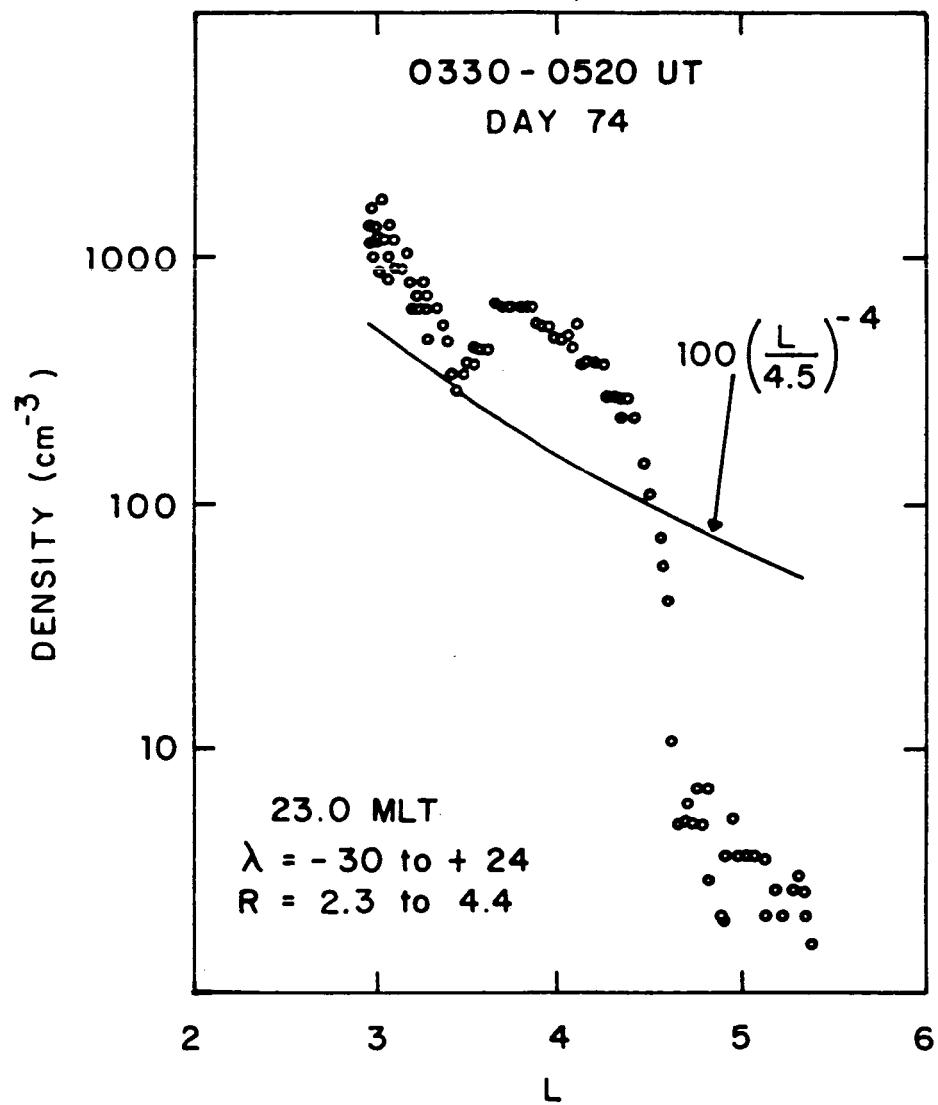


FIGURE 13

DYNAMICS EXPLORER 1  
MARCH 15, 1982  
0330-0520 UT

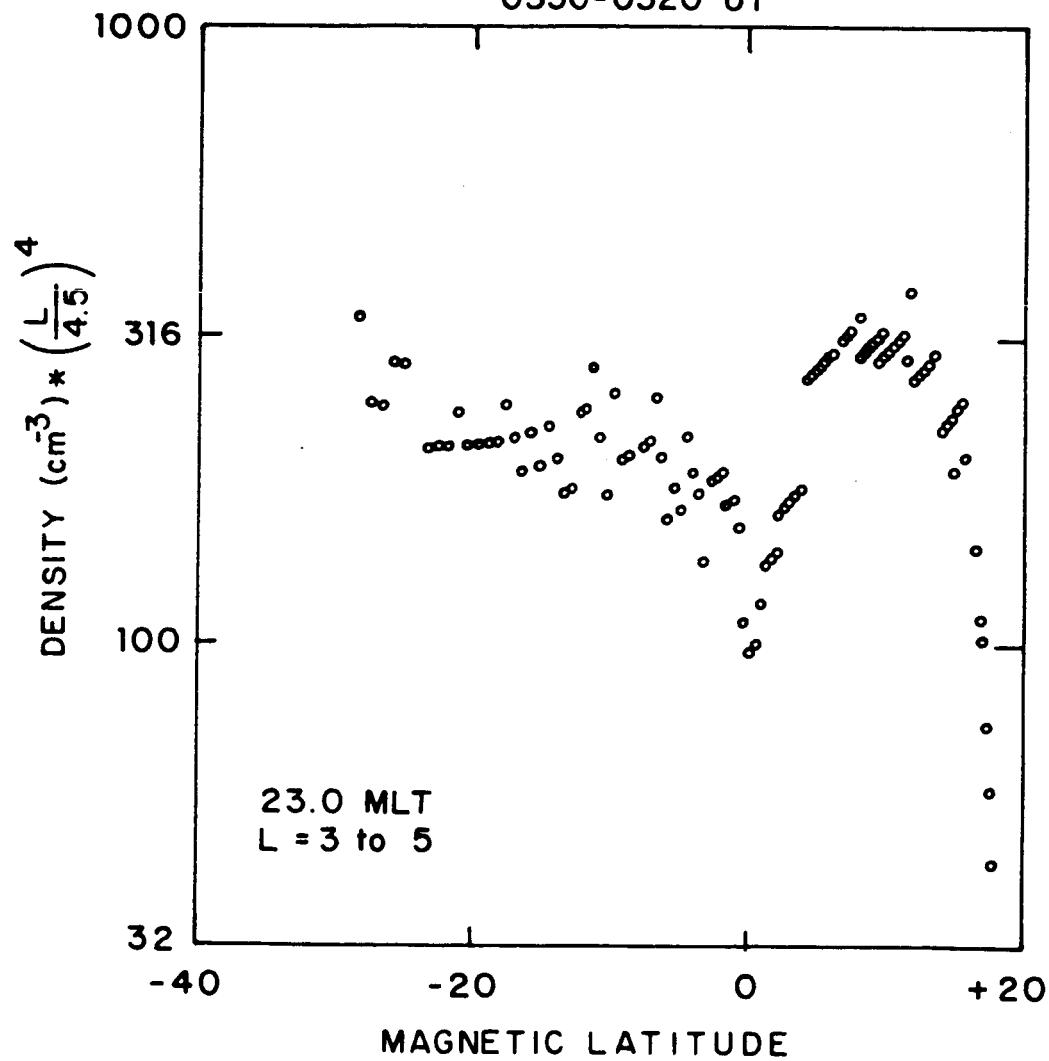
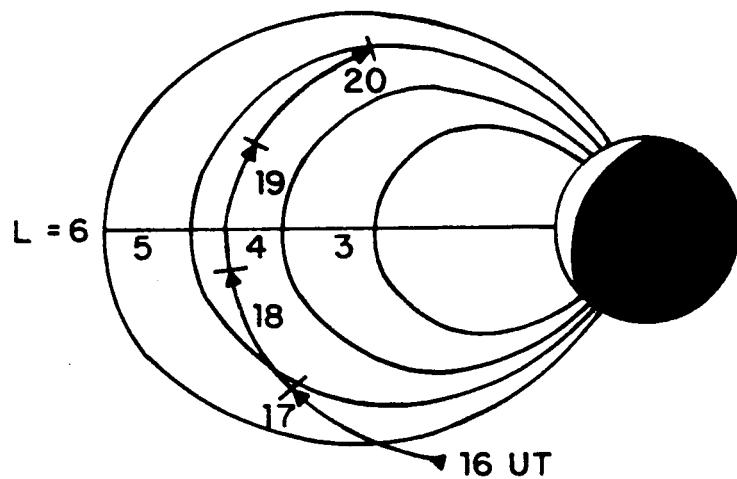


FIGURE 14

DYNAMICS EXPLORER 1  
JULY 18, 1982



SM COORDINATES  
15 MLT  
DAY 199

FIGURE 15

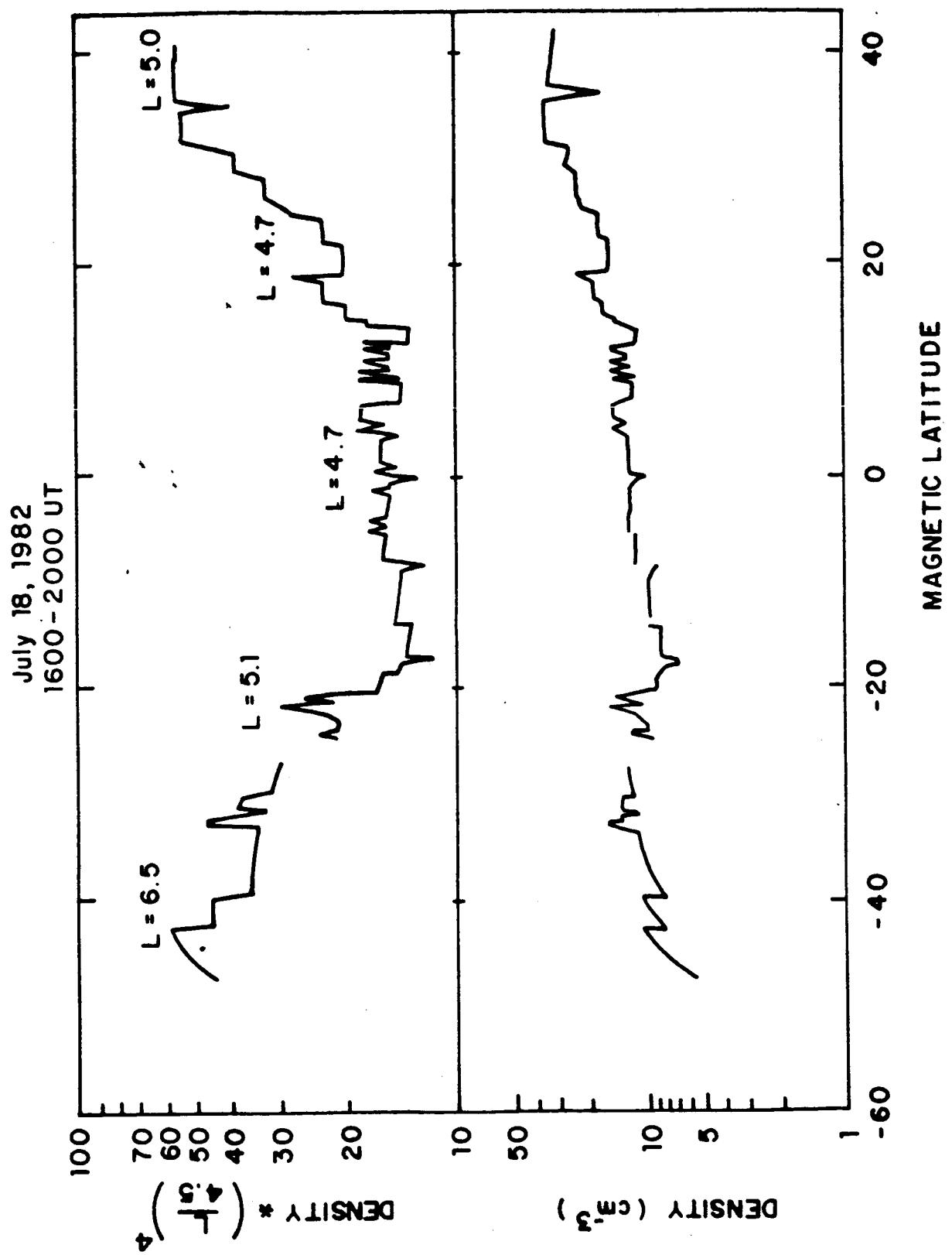
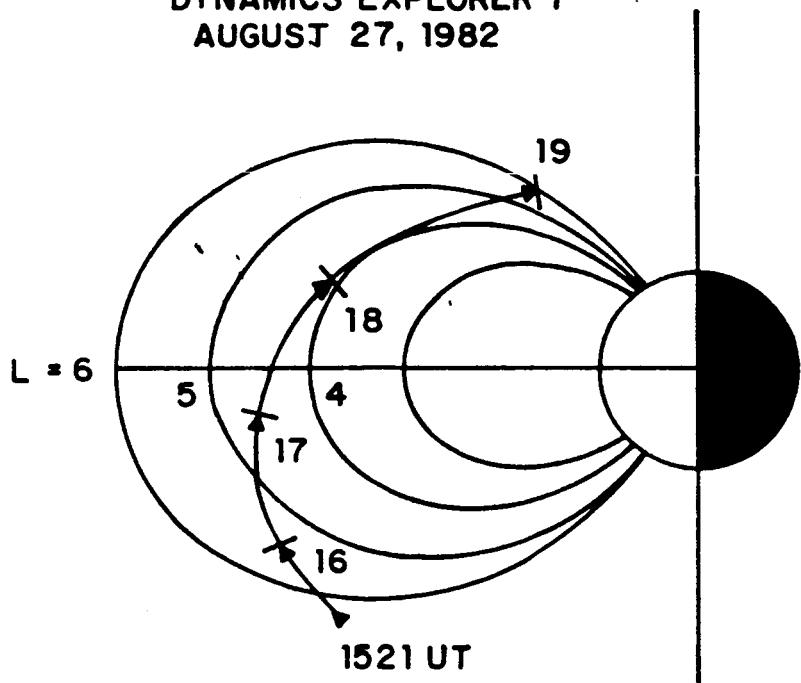


FIGURE 16

DYNAMICS EXPLORER 1  
AUGUST 27, 1982



SM COORDINATES  
12 MLT  
DAY 239

FIGURE 17

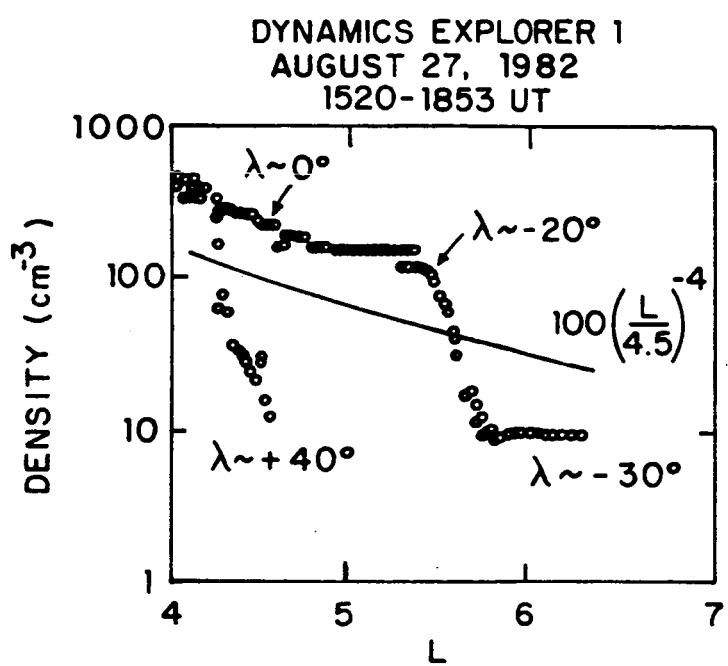


FIGURE 18

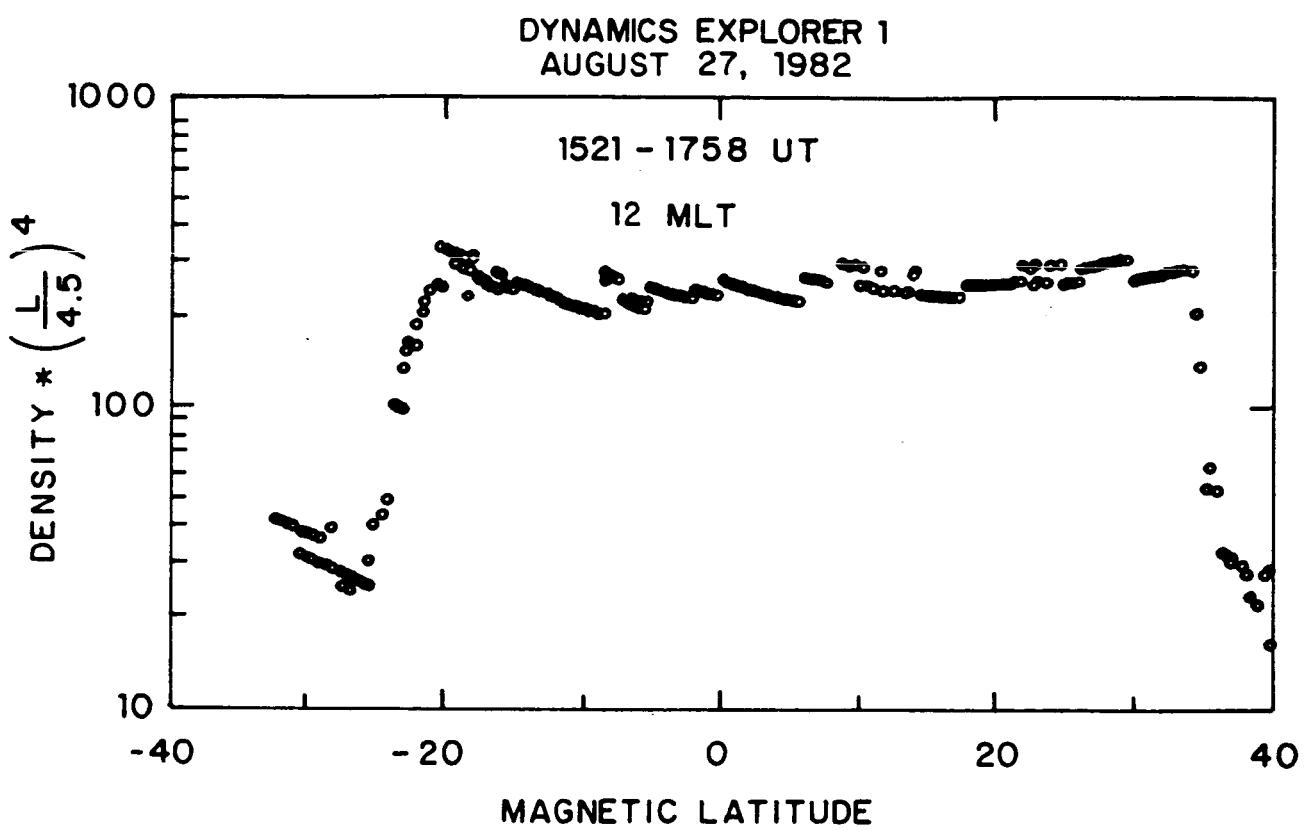


FIGURE 19